LEVELS OF COMPREHENSION DEVELOPED BY NINTH GRADE SCIENCE STUDENTS DURING A TEACHER-PUPIL DEMONSTRATION ON PHOTOSYNTHESIS

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CHAPTER I

INTRODUCTION

Recently there has been much criticism of science teaching. Some scientists have been concerned that science was not taught either as an understanding or as an enterprise. They think that science teaching should reflect the nature of science and it should harmonize with the scientific point of view. The lack of orientation in science teaching and the failure to teach modern science have concerned many groups.[1]

It has long been known that the most effective learning results from situations in which the learner is actively engaged. This active engagement includes the learner's understanding and acceptance of the purposes to be fulfilled. Good teachers have utilized this principle for years. In the teaching of science, teachers must sometimes forget that "doing" is an essential part of the learning process. Often, they are tempted to try to recover the experiences of all the scientists of all the ages by telling the learners what the achievements of these persons have been. In addition, teachers attempt to give the students logical, formal

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[1]National Society for the Study of Education, Rethinking Science Education, Fifty-ninth Yearbook, Part I (Chicago: University of Chicago Press, 1960), p. 7.

organization of science and tell them what the applications of the facts and principles are. This task is so great, that too often, science teaching has become science telling.

I. THE PROBLEM

Statement of the problem. Science curricula in the junior high schools for many years has been the dumping ground for the high school materials that were not being taught at the secondary level. Consequently, very little concern has been given to the quality of work that could be taught at the seventh, eighth, and ninth grade levels. Many of the present-day texts offer general science courses over basic sciences with insufficient thought by the authors on improving the quality of learning by stimulating the thought processes of the students for comprehension during teacher-pupil demonstrations. The present problem was to determine what levels of comprehension junior high students in the ninth grade develop during a teacher-pupil demonstration on the factors which affect the rates of photosynthesis in an Elodea plant and to categorize these levels of concepts.

II. DEFINITIONS OF TERMS

Concepts. Concepts are abstractions which organize the world of objects and events into smaller number of categories,[1] and in this study, concepts will be used to identify

[1] Ibid., p. 33.

relationships existing between factors and rate of photosynthesis.

Different levels of comprehension. Different levels of comprehension are degrees of understandings that are developed by students during an experiment. The higher the degree, the more complex the level of understanding.

Variable factors. Variable factors are those factors which can be controlled in laboratory situations which influence the outcomes of a scientific investigation. This report will use the factors of light intensity and temperature.

Teacher-pupil demonstration. A teacher pupil demonstration is an experiment involving a teacher being aided by students in carrying out a series of planned experiments with the optimum help of students.

III. JUSTIFICATION OF STUDY

It has been said, "It takes fifty years for educational theory to become practice in the schools."[1] Science teaching in the secondary schools is entering the most critical years of its history due to the ever-increasing technological progress in space and atomic energy.

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[1]Robert H. Carleton, "Improving Secondary-School Science," Rethinking Science Education, Fifty-ninth Yearbook, Part I (Chicago: University of Chicago Press, 1960), p. 33.

In many respects the distance between theory and practice in the schools science program is still too wide. "The mere understanding of scientific facts does not constitute understanding of science. Learning studies have shown that mere exposure to science does not achieve understanding."[1] "Although a large portion of the population of the United States has been exposed to science in the schools, the scientific illiteracy of the public mind is appalling."[2]

The products of the science instruction, as represented by the average citizen, are disappointing. Science education in the future must break through to the behavior patterns of the average citizen. To achieve desirable changes in behavior, learning experiences involving the methods and attitudes of science must be taught. Furthermore, the facts, concepts, and generalizations of science should become means toward the development of desirable behavior patterns rather than ends themselves. These commitments represent a major challenge in science education in the future.

In the heat of present concern about the improvement of secondary-school science, there have been numerous proposals to manipulate present courses, to introduce new courses, and to rearrange present courses as to sequences. It is therefore important that these proposals be evaluated in the light of clearer comprehension of the purposes of

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[1]Ibid. [2]Ibid., p. 60.

science teaching and a clearer insight into the nature of learning experiences by which students can be expected to attain comprehension.

Definitive research regarding the nature of science concepts that can be learned by pupils at each grade level is lacking. There is evidence, however, that the background of experience of the learners is a primary factor in determining their capacity to conceptualize in science.[1] With students coming from the lower grades into junior high school with more experience in science, it is reasonable to expect them to be able to work with concepts that before were considered beyond the comprehension of average students.

Research also reveals a wide range or variation at any grade level in the ability of students to conceptualize.[2] Even though the junior high science students pursue the same relative science program from kindergarten through grade six, one cannot assume that they have all reached the same level of achievement. In fact, the better the science program in the elementary grades, the greater the variation of achievement will be by the time the students reach junior high school. This has a number of important connotations for the development of science courses in grades seven, eight and nine. Since an expansion has taken place in the lower

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[1] Katherine E. Hill, Children's Contributions in Science Discussions (New York: Bureau of Publications, Teachers College, Columbia University, 1947), p. 24.

[2] Ibid., p. 44.

grades, much of the traditional general science units will no longer be included in the junior high curriculum. Thus, more complex units of science content from the high school science curriculum can be stressed at the junior high level.[1]

Junior high science courses should provide for a wider range of learning experiences than is generally possible for the elementary level. Greater provision should be made for a laboratory type learning situation in which the students can actually carry out an experiment which they have actually thought out rather than from a work-book type experiment in which they are told exactly what and how they do it. This is merely a cook-book type situation and is not considered very enriching.

Brandwein has found that pupils taking science in the normal way, with little or no laboratory work, elect fewer science courses.[2] Other research shows that laboratory experiences in general science can be used in developing understanding of selected science principles.[3] Thus, if the span from elementary school science to senior high school science is to be bridged in a developmental sense, laboratory

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[1]Helen E. Hale, "Quality Science for the Junior High School," *The Bulletin of the National Association of Secondary School Principals*, XXXXIV, No. 260 (December, 1960), 44.

[2]Paul F. Brandwein, *The Gifted Child as Future Scientists* (New York: Harcourt-Brace and Company, 1955), p. 74.

[3]*Ibid.*, p. 148.

work must become a common practice in the junior high school science program.

IV. BRIEF REVIEW OF THE LEARNING PROCESS

The unique purpose of the schools is to create within the students certain types of cognitive learning and standards of critical judgment which are not acquired through day-to-day social contacts in the community or home. The school should give the students a firm foundation of basic knowledge based on skills, attitudes, and understandings. Therefore, educators must primarily be concerned with what the child learns, the conditions under which different individuals achieve this learning most rapidly, and the evidences each child gives of having achieved the objectives of science education.

The readiness of each individual pupil and the structure of the subject come together in the process of "learning." Teaching is the procedure by which teachers attempt to expedite this learning. Without serious and continual study of the complex learning processes required in sciences, valid science teaching methods will be developed slowly.

Help in understanding the learning processes must come from data collected by psychologists. However, very little research is available. When the Advisory Board on Education of the National Academy of Sciences considered means to improve science education, many questions were raised about the status of basic research on fundamental processes of learning. Examination indicated that relatively little direct attention was given to these problems by experimental psychologists. This makes it very difficult to acquire meaningful data about fundamental concepts and theories of the learning processes. However, it is of vital importance that sound principles be available for guidance in developing sound programs and improving teaching in science.[1] Furthermore, a group of psychologists reported to this same Academy, "There was general agreement that research on intellectual development and especially on problems fundamental to the understanding of intellectual learning in the schools, has been seriously neglected."[2]

Before any courses of study can be fully developed to be of the utmost help in aiding students to understand and comprehend science, the educational and psychological processes must be fully understood.

In a second report on the contacts between psychology and education, the Academy members observed that between 1890 and 1920, those who did research in these areas also assisted importantly in the shaping of educational developments, theories and methods in use today. In recent years this close liaison has been largely lost, especially between practical

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[1] Psychological Research in Education (Washington: National Research Council, National Academy of Sciences, 1958), p. 1.

[2] Ibid., p. ii.

educators and research psychologists.[1]

Although it cannot be assumed that older children learn in the same manner or with the same emphasis as younger children, suggestions from work with younger students should help in investigating how to proceed with the latter group. Particular attention should be focused upon the conceptual processes by which the younger children form categories, and whether these deal with static or dynamic attributes of phenomena. Grouping into categories is one aspect of concept formation. Major research already verifies that concept attainment in acquiring the ability to distinguish between events and objects which should or should not belong in a given category is possible.[2] If educators wish children to develop skills in making applications and in judging the desirability of anticipated reactions, then science would seem to offer the ideal area of experimentation.

However, educators have very little clear evidence as to how and when the developing child, provided with selected experiences, can form dynamic classifications. To truly understand the learning processes of students, their home and school backgrounds, general intellectual ability, sex,

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[1] J. S. Bruner and J. Geodnow, The Study of Thinking (New York: John Wiley and Sons, Inc., 1956), p. 12.

[2] A Proposed Organization for Research in Education (Washington: National Research Council, National Academy of Sciences, 1958), p. 4.

age, and other less obvious attributes must be taken into consideration.

In their efforts to improve the planning and operation of science courses, most teachers are severely hampered by lack of adequate rationale of teaching and learning.[1] Such a rationale should contribute to the production of instructional plans as clear and as operational as possible. Such planning requires a knowledge of how children learn concepts, but teachers cannot wait until "all" is known about the learning procedure before taking steps to further progress in this important area. Certainly what is now known can be profitably incorporated into the design of planning schemes.

Teachers need some framework which will aid them in making explicit plans in advance of each day's classroom activities, the nature of the experiences to be learned, and the behavior patterns sought from pupils as exact evidence that learning has taken place. There already exist several suggestions as to the possible nature of such schemes or formats. One phase of this research has been to survey existing psychological knowledge to see whether such formats are consistent with what is known about the learning processes. The second problem is to put into practice the teachers' abilities to design such plans and use them effectively. Teachers must therefore be able to read the scripts and visualize the

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[1] Ibid., p. 22.

pupils' behaviors. A format that is psychologically sound, can facilitate the learning of lessons, and is intelligible to science teachers, will certainly contribute to the improvement of the teaching of science.

Although the learning process and its associated problems cannot be considered apart from the learner, there are some difficult problems confronting science educators today which are mainly concerned with the learner, especially different types of learners.

V. CURRENT RESEARCH FOR IMPROVING SCIENCE EDUCATION

Donald Decker, past president of the National Science Teachers Association and director of the department of Science Education, Colorado State College, stated that a good science program should be based on the following criteria:

> Continuous experiences in science must be available from kindergarten through grade twelve. Students at each grade level can learn some concepts in each area of science. Science concepts studied from K-3 should allow the child to describe his environmental situation and show him that science bases ideas on facts. Grades three through six should enable children to describe and explain their environment, equip children with a plan for a solution of simple problems, and how to select pertinent information without bias. Science, grades seven, eight and nine should allow children to describe, explain and evaluate their environment, develop problem solving skills that enables them to analyze evidence and make generalizations. Senior high students should describe, explain, evaluate and predict causes and results of activity in major areas of science, become proficient in problem solving, and base conclusions on facts.[1]

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[1]Donald Decker, "Quality Science Education," The Bulletin of the National Association of Secondary-School Principals, XXXXIV, No. 260 (December, 1960), 34.

A research project carried out by the Englewood Public Schools, Englewood, Colorado, was directed toward the collection of information to prove or disprove two assumptions related to qualities of science concepts developed by elementary school children.[1] The quality concepts in this report are descriptive ideas of classes of objects or events used by students in a learning situation.

> The two assumptions in this report were: (1) students at each grade level develop different qualities of concepts or degrees of completeness during each science lesson; and (2) the science concept a student does develop may be a better indication of the ability of the students to develop science concepts than his intelligence quotient.
> The general findings of this study revealed: (1) that students do develop different qualities of concepts, (2) teachers also differ in their abilities to teach subject matter to different classes, and (3) the ability of teachers to teach a science lesson plan is as important in science education as the interests and abilities of the students.[2]

VI. ANTICIPATED OUTCOMES OF THIS STUDY

This field report will take into consideration the current data from educational and psychological research in developing a science unit on photosynthesis for junior high school ninth graders.

Teachers many times fail to take into consideration all of the factors which will influence the outcomes of a

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[1]Rolland G. Walters, "Quality Science Concepts of Science Students in the Englewood School District" (Englewood, Colorado: Englewood School District Board of Education, 1960). (Mimeographed Report.)

[2]*Ibid*., p. 4.

scientific experiment. Thus, if the teachers fail to control these factors in demonstrations, it will be very hard for the students to carry out a true scientific project in a scientific manner.

Therefore, since current research data at the elementary school level verifies that students can and do develop different levels or degrees of concepts, it was assumed that a closely knit unit on photosynthesis will offer pupil experiences which would allow the development in students of different levels of understandings or conceptualizations at the junior high school level. It was the aim of this study to verify the assumption that students can develop different degrees of relationships and understandings and to categorize these levels of concepts. There was no attempt to correlate these different degrees of concepts with the student's intelligence quotient.

CHAPTER II

A DESCRIPTION OF PROJECT

I. THE PROJECT

The purpose of this study in junior high school science was to determine what levels of conceptual attainment may be developed by individual students during a controlled teacher-pupil demonstration on the factors and variations of certain factors which affect the rate of photosynthesis in Elodea plants.

The demonstration was based on two factors which affect the rates of photosynthesis: (1) light intensity; and (2) temperature. Students were to assist the teacher in setting up a group of experiments to demonstrate how these factors operate.

During the progression of the demonstration, students were to be asked questions by the teacher concerning results of observable phenomena. An example of this would be carried out during the trial on light intensity and variations of this. The students were to vary the distances from the plant to the light sources and record the changes in the number of gas bubbles given off by the Elodea plant, thus showing a numerical increase or decrease in gas production in relation to light source distances. The students were to graph these data on the blackboard and show relationship of gas bubbles in comparison to light intensities. The only variable factor of this light intensity experiment was the distance of the light source from the plant. The water temperature and ingredients of the medium in which the plant was placed, the lamp wattage, the per cent of environmental carbon dioxide, and the chlorophyll content of the plants was constant or controlled, as set forth in the actual demonstration.

Each student was to write a summary of the experiment in his own words and state the relationships which exist between the rate of photosynthesis and the factor under study. It was assumed that students would develop different levels of understandings. The levels of complexity could be classified as numerical degrees of relationship. An example of these are: first degree, second degree, and third degree relationship. The higher the degree of relationship, the more detailed and involved is the concept developed.

In this demonstration on light source distance, a student might summarize by stating that light is necessary for plants to carry on photosynthesis. This would be called a first degree relationship. A concept, the greater the intensity of light, the greater the rate of gas bubbles, would be of second degree complexity. A third degree relationship would be if the student stated that the rate of photosynthesis is an inverse proportion in which the photosynthetic rate varies with the square of the distance from the Elodea plant to the light source. The purpose of the study was to determine the levels of understanding as exemplified here.

II. HOW TEACHERS CAN GET OPTIMUM RESULTS FROM THIS UNIT

Teachers should take into consideration all of the variable factors which might affect the outcomes of such a demonstration. The scientific factors might include the environmental conditions such as whether the Elodea plants were light or dark adapted. This could have an effect on the quantity of gas bubbles given off in a certain interval of time at a given light intensity. The experimental Elodea plants should have a common background. This would include growing plants in the same aquarium and irradiated with the same intensity of light. The physical state of the Elodea plant is important also. The plants should all be of the same degree of green coloring. Another factor which should be recognized is the manner of cutting the Elodea twig. The base of the plant should be cut at right angles to the plant's axis with a sharp instrument. After cutting the sprig it will be helpful to squeeze the cut end between the thumb and index finger to decrease the area exposed. This will result in the formation of gas bubbles of uniform size and rate of production more constant. Care must be taken to insure accuracy in reading the light meter and thermometer.

Individual differences will have an effect on the accuracy of measurement, scale readings, data recording, mathematical calculations and other observations. It is also important that a minimum of background differences occurs within the group concerning the content of the topic. Thus, each student should be given a preliminary statement of the work to be covered. This will act as a "refresher course" for the students. It should include the essential information on the topic. It is very important that all students review this material very thoroughly. It might be necessary to include some of the repetitive drilling, but this must be held to a minimum since it could have an adverse affect on the expected outcomes the students develop.

The students should carry out as much of the demonstration as possible under the teacher's observation. This should increase their desire, stimulate interest and give them a sense of direction in conducting their own experiments later. Accurate recording of data should be explained by the teacher as to its importance in the final outcome. These data should first be placed on the blackboard so that accuracy in recording can be scrutinized by all students. In the present study, the actual interpretation of this graph should be left to the discretion of the students. The teacher should offer very little assistance in this interpretation since the object of this project is to determine the degree of understanding the students develop from the presentation of the experiments. The students should also be encouraged to do their own work and not let classmates compare relationships since the results would not be valid with their own range of scientific capabilities.

III. REVIEW OF PHOTOSYNTHESIS FOR STUDENTS

The energy upon which all life depends comes from the sun in the form of radiation called light. This energy cannot be used directly, but green plants employ it in photosynthesis--light building. In this process, the burned out carbon present in the air as carbon dioxide is rebuilt into organic compounds which are essential for life. Other materials besides carbon dioxide which are important in photosynthesis are water and sunlight, and sunlight is a crucial limiting factor. Few plants do well without more than 10 per cent of full sunlight, and fewer still survive with 1 per cent. In contrast, water and soil fertility are primary limiting factors for plant growth but not the processes of photosynthesis.

Imagine looking at a factory from the outside. You see trucks delivering nothing but mineral water and air. From the other end of the factory, you see trucks carrying out carloads of sugar. Fantastic? Not at all! Such an active chemical factory is right outside your window in the summer time. This factory is the green leaf. It is not so simple to the scientists who have been trying to investigate the chemical processes that take place within the leaf. For here the basic ingredients of life are formed, without which man and all animals would starve, and, without oxygen, most life could not be sustained.

The chief function of the leaf is making (synthesizing) a new chemical compound from the materials at hand, carbon dioxide and water. Plants which carried on photosynthesis ages ago provide the coal and petroleum used today. Sugar is used by plants to maintain life and manufacture a wide variety of other compounds.

How exactly does a plant manufacture sugar? From the soil, the plant absorbs water. Air enters the leaf through openings called stomates. Water and carbon dioxide from the air enter the cells of the leaves. Chlorophyll-containing cells exposed to light convert water and carbon dioxide into a new product--sugar. Since light is required for the synthesis of sugar, this process is called photosynthesis (from the Greek word, "putting together by light"). Light is a form of energy. A green leaf converts light energy into chemical energy which binds the elements together into a sugar molecule. This can be proven by placing sugar in contact with sulfuric acid: its molecules will break down, releasing heat and sometimes light. Without the energy of light, the leaf cells could not synthesize sugar.

The general chemical equation for the reaction of photosynthesis is:

$$6\ CO_2 + 6\ H_2O + \text{Energy} + \underrightarrow{\text{Chlorophyll} + \text{Enzymes}}\ C_6H_{12}O_6 + 6O_2\uparrow$$

Conditions Necessary For Photosynthesis

The rate of photosynthesis is influenced by temperature, intensity of light, amount of carbon dioxide present in the surrounding environment, and the abundance of water. A few simple algae are able to live in hot springs and carry on the process at extremely high temperatures. Other algae floating in the Arctic Ocean carry on the process at almost freezing temperatures. The great majority of plants manufacture their food at temperatures intermediate between these two extremes. Plants differ a great deal in their light requirements. Leaves on many plants adjust to the light by growing into positions where they receive the greatest amount of sunshine. An adequate supply of water in the soil is also necessary. The energy stored in 180 grams of sugar (glucose) is approximately 672 kilocalories, or enough energy to heat water for a good shower bath. This energy is obtained from light. A green chlorophyll molecule that has absorbed a unit of light has a heat energy level equivalent to a temperature range to tens-of-thousands of degrees. Since this is enough heat energy to destroy a plant instantly at this high temperature, the energy is used during photosynthesis within thousanths of a second or changes gradually to heat and spread so fast over so many molecules within the plant that no harm is done.

The intensity of sunlight from dawn to sunset varies with the elevation of the sun and atmospheric conditions. Fully exposed leaves can use no more than one-fifth to one-half the total light available with normal amounts of carbon dioxide available. Therefore, about one-third of the total sunlight will permit maximum photosynthesis. Most plants will make growth with as little as 10 per cent sunlight. The greatest harm of sunlight occurs when the intense heat dehydrates plants.

Sunlight alone cannot do the whole job of photosynthesis. In the leaf, there are substances which help sunlight change carbon dioxide and water into sugar. Chlorophyll and other enzymes are these substances. Thus, sunlight with the help of these enzymes converts the raw materials, carbon dioxide and water, into glucose. Actually, the process of photosynthesis is not this simple. Many intermediate steps take place and scientists do not know all of the steps. Much research has yet to be done to unravel this secret of nature.

Without carbon dioxide, formerly considered a waste gas, chlorophyll cannot perform this work. The amounts of carbon dioxide gas present in the atmosphere are only about three parts per ten thousand. In working with water plants such as Elodea it is very important that a constant source of this gas is available in the fluid environment. To insure the necessary concentration of carbon dioxide, a solution of .25 per cent sodium bicarbonate is mixed and about 2 cc.

(cubic centimeters) of this solution is added to every 100 cc. of aquarium water. This will provide a source of carbon dioxide without the need for animals.

A test for the absorption of carbon dioxide from water by green plants in light is revealed through the change of color of an indicator, brom thymol blue. It is blue in alkaline (base) solutions and yellow in an acid medium. It has a very narrow range in pH from 6.0 (yellow) to 7.6 (blue), so that slight changes in the solution (hydrogen-ion) show up quickly. Thus, a slight increase in acidity, as when carbon dioxide is added to the solution, will change the blue (alkaline) color to yellow. When carbon dioxide is absorbed, as in photosynthesis, the yellow color (due to carbon dioxide in solution) is changed back to blue. This solution can be prepared by dissolving 0.5 grams of brom thymol blue in 500 cc. of water to make a 0.1 per cent solution. To this add a trace of ammonium hydroxide (one drop per liter) to turn the solution deep blue. In another beaker dilute the 0.1 solution into the environmental water and make sure the whole solution is still deep blue. Then breathe through a soda straw into this solution until it just turns yellow. Thus, any change in the solution content of carbon dioxide will turn the solution back to deep blue, if it has been absorbed by the Elodea plant. Phenol red is another indicator that can be used. It has a narrow color range of pH 6.8 acid to 8.4 alkaline. As the carbon dioxide is absorbed, the color change is from yellow (acid) to red (alkaline). It is difficult to find other methods to show the carbon dioxide intake by water plants that are actually carried out in quantity.

Experiments

There follow experiments which will be used to test what levels of understanding occur in the students' participation in the demonstrations. Each student will be given a complete set of experiments which will include the review of photosynthesis and questions to be answered. All directions will be included so that direction will be maintained.

Experiment I: Light Intensity Variable

Arrange your materials and supplies near a sink so that overflow water will present no problem. The apparatus should be assembled as in the attached "Apparatus Set-up" schematic. What scientific reason can you deduce for the plastic baffle plate being drilled with holes in the upper and lower one-third? (1) Could you devise a simple test to check your response? (2) What is your concept as to why it is or is not important that a flow of the environmental media be maintained? (3) The "Carbon Dioxide Bubble Control" should be placed on the opposite side of the light source. Why? (4) What is the purpose of the calcium carbonate chips being placed in the bottom of this control flask? (5) What chemical test can you use to prove your conclusion? (6) Would this chemical have any adverse effects on the Elodea plant? (7)

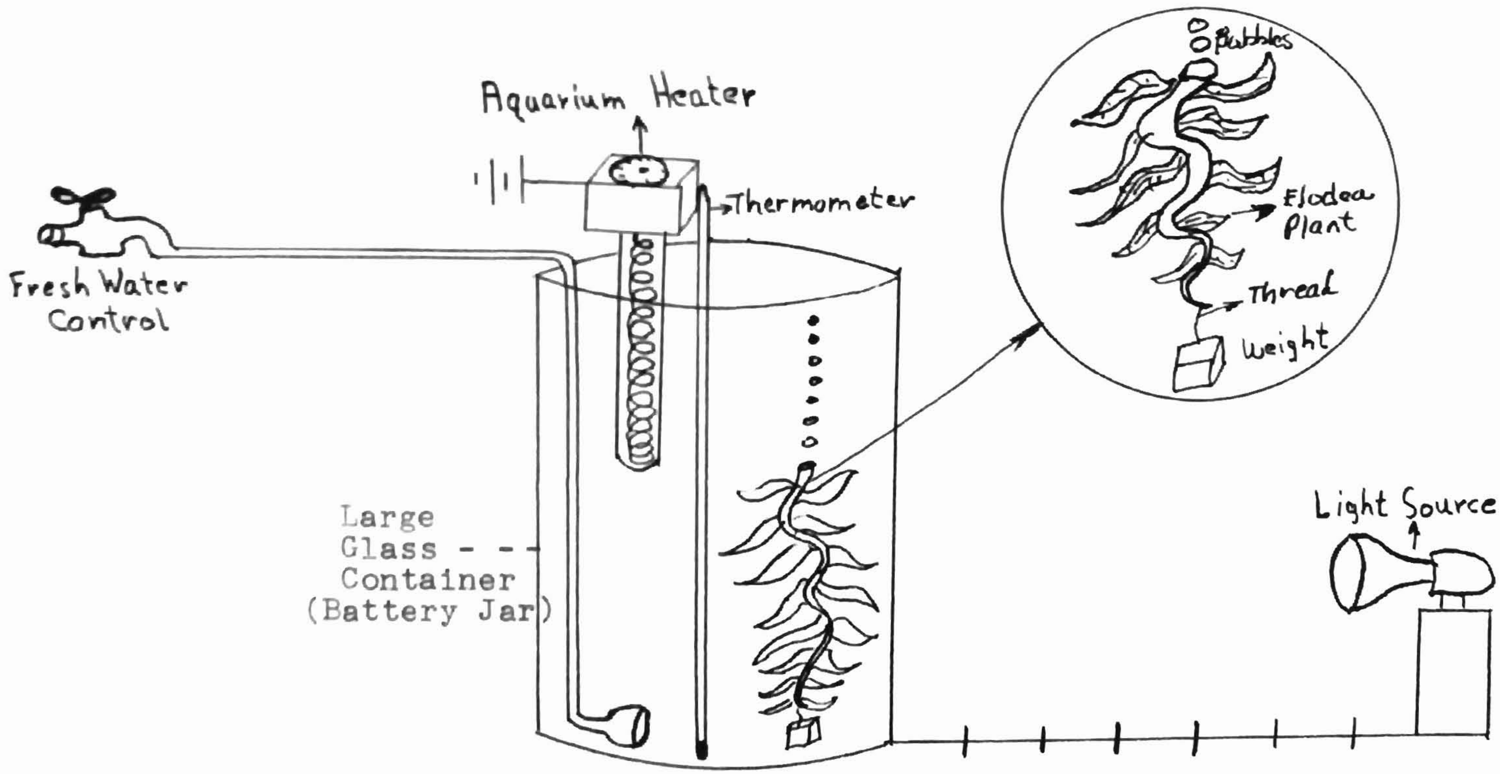


Figure 1. Apparatus set-up.

Place the thermometer in the correct position on the same side as the carbon dioxide control. If necessary, wire the thermometer to the baffle plate. Make sure that the thermometer can be read from outside the container. Attach the environmental heat control but allow at least five minutes before plugging into the wall socket. Why? (8) Next, position the cool water temperature control at the bottom of the jar. If necessary, this can be weighed down with weights to keep it in the correct position on the bottom facing the baffle-plate.

After positioning all the apparatus on the drain board or table, turn on the cool water temperature control until the jar runs over. Shut off the water intake and wait for at least five minutes before making any trial runs with all electrical connections turned on. Be very careful that all electrical wires are insulated and positioned above the water so no direct contact results. When the time has elapsed, turn on the temperature control to a 70 degree temperature Fahrenheit. What temperature would this be on the Centigrade and Kelvin scales? (9) Since the temperature is to be one of the major controlled factors, it is very important to make several adjustments until the environmental media is accurate. What type of scientific conclusion can you formulate as to how this factor could have an adverse effect on the outcomes? (10) It will take several hours for the media temperature to reach its proper range.

The factor which could adversely affect the experiment may be the environmental media in which the plant has been growing. Thus, it is very important that the plants be placed into the tap water several days preceding the experiment.

Light intensities will be used as the variable factor. The plants are placed in an artificially lighted environment for several days before doing the experiment. Why? (11)

The light source should now be positioned so that it can be easily moved. A 150 watt reflectorized lamp will serve as an excellent light source.

The final step will be to properly take the selected Elodea plant, and, with a sharp knife or razor blade, cut the base of the stem at right angles to the apex of the stem and then pinch this end between the thumb and index finger. This will cut down the exposed surface area where the expelled gases will be released. To hold the plant in the area between the upper and lower holes in the baffle-plate, tie a piece of thread to the very tip of the plant and weigh it down with a piece of lead foil. The Elodea plant will remain submerged in an inverted position. Why is it important that it be inverted? (12)

Place the light source at a distance of thirty-six inches from the Elodea plant and then sequentially move the lamp nearer. It will be important now, as the lamp is brought nearer, to watch the temperature variations within the media.

What controls can be used to control this? (13) It will be important that a very accurate recording of the data be kept. Can you devise a chart for the recording of the data so that it can be easily read? (14) Also, it will be very valuable to graph the data onto the graph so that the numerical data obtained will have a statistical relationship as the experiment progresses. What type of graph can you design to show this? (15) A light meter should be used to give numerical data on various light intensities.

Do some research reading on light intensities and how light is measured. What units are used to measure light? (16) Can you make a light-intensity chart which will show the various intensities at the sequential distances before the experiment is started? (17) This will be a great help in carrying out the experiment.

The pH of the environment should also be kept by sample testing with the hydrion paper slips. What effect will this have on the rate of gas production? How could you design an experiment to prove this? (18)

Graphs of quantitative data are important in scientific communication. When you are graphing a process, take pains to plot the points accurately and to connect them with smooth lines. Label the quantities plotted on the vertical axis (ordinate) and horizontal axis (abscissa) along the scales, and provide the entire graph with a concise title. When you express data quantitatively, do so as precisely as possible, using the metric system; avoid the use of data which indicate greater precision than what is allowed by the instruments. To state that the thermometer reading was 30.5 degrees Centigrade would be erroneous since the scale on the thermometer is marked in whole degrees. To make use of such data is unscientific and thus unreliable. The same is true with averaging results, carrying them out several decimal places when all measurements were made using one decimal place. This leads to a false impression of accuracy. Always, round the average to the same degree involved with the instruments used.

When all of your data have been recorded and graphed it will be time to analyze and interpret your information. Can you see any type of relationship on your numerical graph between light intensities and gas production by the Elodea plant? (19) What type of relationship can you state that can be verified by your data? (20) (This is the most important part of the experiment. You must think this relationship out very carefully, doing your own work in formulating your concept. It must be verified by your data.)

Can you think of any ways that could be introduced or left out that would make this experiment more meaningful? (21) In your opinion, do you feel that a lesson taught by this process has more merits and is therefore more meaningful than if merely read from a scientific review or book? (22) Which part of this experiment did you like most doing? (23) What did you dislike most about the demonstration? (24)

Experiment II: Temperature

This experiment will be done with the same type of apparatus set-up that was used for the light intensity experiment. The variable factor in this demonstration will be the sequential change of environmental media temperature.

The procedure will be identical to the previous experiment except that the aquarium heater will be used to attain the desired temperatures. Ice will be used to attain temperatures below that of the water from the tap.

What other factor must be controlled if the variable factor in this experiment is the temperature? (1) At what distance do you think the light source should be placed to obtain the maximal light intensity with the least amount of additional heat? (2) Where can you find data to substantiate your conclusion on this factor? (3) At what range of the temperature scale do you think would be best to start from, the lower or higher range? (4) Why? (5) (Think this out very carefully and be sure you have considered all the possible advantages and disadvantages for basing your conclusion.)

Since a lower temperature range will be required in this experiment, what type of artificial means do you think will work the best? (6) Considering the material you will use for this part of the experiment, what is the lowest temperature reading you can obtain to use as a starting point in recording your data? (7) How will you proceed to verify this conclusion? (8)

Since plants are very similar to humans, about how long will it take the Elodea to adjust to this abnormal environment? (9) Why is this an important factor? (10)

It will be very important to keep the temperature controlled to the nearest whole degree, since any greater change will make the results invalid. After you have begun your work, about what degree of temperature range will you use between the sequences? (11) Scientists sometimes refer to the temperature factor in photosynthesis as the "Q-10 factor." Can you deduce any meaning from this term after carefully recording your data on temperature effects on the rate of photosynthesis? (12) You may have to do some research reading on photosynthesis to find the exact definition of this.

Before recording any of the data in final form, can you think of any factor or variation of factors which should have been checked but which may have been overlooked? (13)

Again, you are to graph your numerical data so that you can plot any changes in your findings. Which factors will you plot on your graph? (14) Remember some of the problems which may be encountered in graphing from the light intensity experiment. A good fundamental scientist always rechecks all his factors before making any type of report since any errors may invalidate all of his efforts.

When all your data have been collected and properly assembled, it is time to graph the results and formulate some conclusions based and verified by your data. Look over your graph and see if you can observe or detect any outstanding numerical changes. Name them. (15) Carefully scrutinize this relationship and formulate a scientific concept which you think best expresses your conclusion. (16) When this has been formulated, carefully read it over to make sure it expresses only what your data show. This is probably the hardest part of the experiment, so use only your data and statistics to base your concept. If your concept is valid and the experiment is easily reproduced by others, it will then pass the scientific test of repetition and verification by others.

From your scientific viewpoint, what is your opinion as to the merits of such a science lesson? (18) Why did you like or dislike all or parts of this experiment? (19)

CHAPTER III

EXPERIMENTAL DATA AND ANALYSIS OF STUDENT RESPONSES

I. INTRODUCTION

The 120 students in ninth-grade science at Central Junior High School in Ames, Iowa, handed in their notebooks with their data, graphs and summaries when all the experiments were completed. These were then carefully read for content by the investigator. The key point of the project was to determine if the students did develop different levels of understanding. This would be based on the degree of concepts written by each student of the effects of light intensity and environmental temperatures on an Elodea plant during the process of photosynthesis.

II. DATA RECORDING

Five classes of ninth-grade students ran the same experiments on temperature effects on an Elodea plant by counting the number of gas bubbles given off during time intervals of one minute. Since slight differences in the exact number of bubbles produced per minute occurred in the different sections, all of these were added together and the average number of bubbles per minute was obtained. Thus, in Table I, the average number of bubbles per minute is shown and these data were given to all the students so that this would not be a complicating factor in the level of understanding arrived at by each student.

The temperatures ranged from a low of 59° Fahrenheit to the high of 99° Fahrenheit in 5° Fahrenheit steps. This range of temperature could be easily obtained using the facilities in the school laboratory. The light intensity of 3200 candle power was selected since it produced a maximum number of gas bubbles during a trial run on how light intensity affects the Elodea plant during the process of photosynthesis. Similar results could have been obtained by using some other light intensity.

TABLE I

AVERAGE NUMBER OF RECORDED GAS BUBBLES GIVEN OFF PER MINUTE DURING PHOTOSYNTHESIS OF AN ELODEA PLANT AT VARIOUS ENVIRONMENTAL TEMPERATURES WITH A CONSTANT LIGHT INTENSITY OF 3200 FOOT CANDLES

Temperature (Degrees Fahrenheit)	Gas Bubbles Given off per Minute
59	4
64	10
69	12
74	12
79	5
84	6
89	4
94	2
99	0

The second part of the designed experiment was to find the effects of various light intensities on the production of bubbles given off by an Elodea plant during the process of photosynthesis. Each of the five sections of ninth-grade science carried out the same basic laboratory procedures on how many gas bubbles were given off with the selected light intensities ranging from 1600 to 12,800 foot candles of power. Since each class reported different numbers of bubbles per minute, all data were averaged to the nearest whole bubble per minute and given to each class to base their understandings on. Table II presents the data made available to all the students.

TABLE II

AVERAGE NUMBER OF GAS BUBBLES GIVEN OFF PER MINUTE BY AN ELODEA PLANT DURING THE PROCESS OF PHOTOSYNTHESIS AT A CONSTANT TEMPERATURE OF 74° F. AND A LIGHT INTENSITY VARIABLE FROM 1600 TO 12,800 FOOT CANDLES OF CANDLE POWER

Light Intensity (Foot Candles)	Gas Bubbles Given off per Minute
1600	7
3200	12
4800	14
6400	14
9600	16
12,800	18

The data presented in Tables I and II were arranged on graphs. These are presented in Figures 2 and 3.

III. CLASSIFICATION OF STUDENT RESPONSES

The concepts handed in by the 120 ninth-grade science students were read and classified into five categories. Some of the samples were hard to place onto a specific group and were placed where the investigator thought they best belonged. The different categories are as follows:

Category A. The Category A group consisted of those students who gave "no responses" to the problems of light intensity and temperature on the rates of photosynthesis. None of these students gave any reasons for their lack of responses.

Category B. The Category B group of students missed the point completely. They had no understanding of the relationship between the light intensity and temperature upon the rate of photosynthesis. One of these students wrote that "if the environmental fluid became too hot due to the heat from the light source, the plants would die."

Category C. The Category C group was called the First Degree Relationship responses. These students stated a verbal understanding of the relationship that light intensity and temperature did affect the rates of photosynthesis in an Elodea

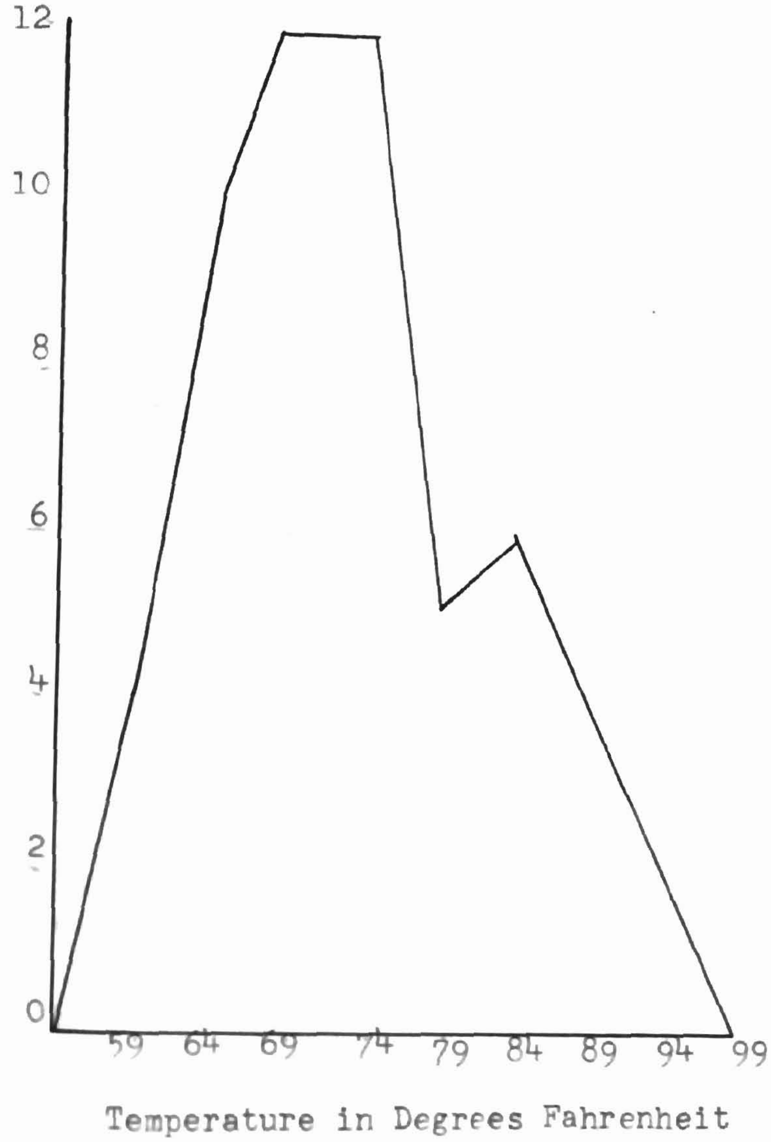
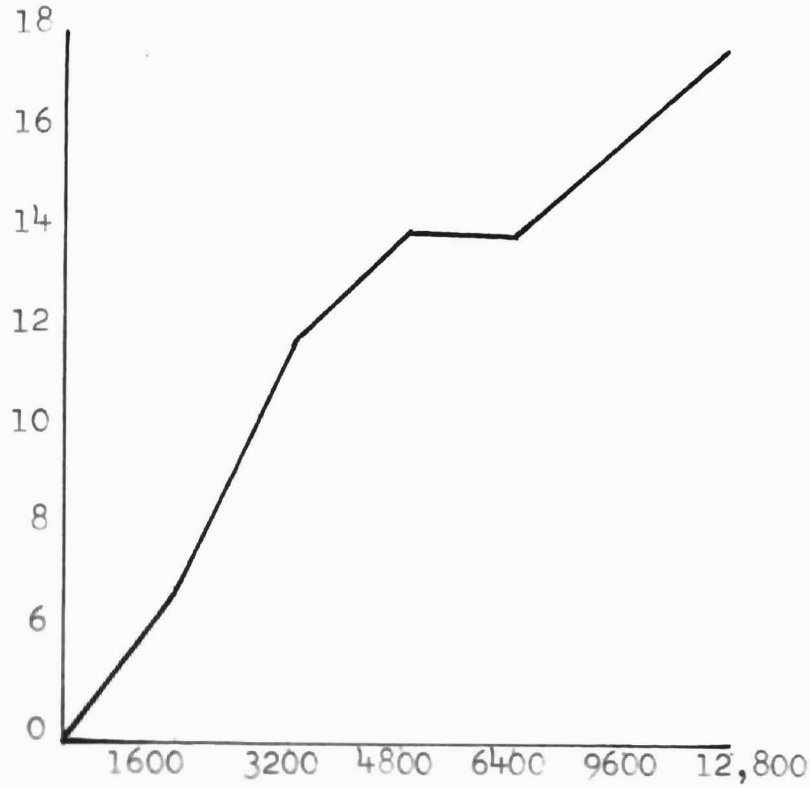


Figure 2. Average number of recorded gas bubbles given off per minute during photosynthesis of an Elodea plant at various environmental temperatures with a constant light intensity of 3200 foot candles.



Light Intensity in Foot Candles of Power

Figure 3. Average number of recorded bubbles given off per minute during photosynthesis of an Elodea plant at various light intensities with a constant temperature of 74° Fahrenheit.

plant. These students stated only a verbal mathematical relationship, that the rates either increased or decreased. An example of this is, "the nearer the light, the greater the rate of photosynthesis."

Category D. The Category D group was labeled the Second Degree Relationship responses. These students responded with direct mathematical and verbal relationships as to the effects of light intensity and temperature on the rate of photosynthesis. These students computed a statistical value from their data and graphs as to a numerical factor relationship. An example is, "as the light intensity is doubled in candle power, the bubble output increased by two per minute."

Category E. The Category E students were labeled Third Degree Relationship responses. These responses were very well thought out in mathematical reasoning. Most of the students tried to formulate a mathematical formula for the relationship of light intensity and temperature on the rates of photosynthesis in an Elodea plant. A good example of these is, "for each 200 per cent difference in candle power, there is a 7.8 difference in the bubbles emitted by the Elodea plant."

IV. SUMMARY OF STUDENT RESPONSES

The responses of the students to the question, "how does the variation in light intensity affect the rates of photosynthesis in an Elodea plant during photosynthesis," and "how do changes in environmental temperature affect the rates of photosynthesis when the light intensity is constant in an Elodea plant," are included in the Appendix.

The responses of the students were placed into two classifications. One class was for the statistical value of the light intensity and the other classification was for the temperature variables on the rates of photosynthesis. The analyses of these responses are included below:

Category A. Light Intensity: twelve students gave "no responses" to the experiment. This was equal to 5.8 per cent of the students involved.

Temperature Variable: twelve students gave "no responses" to this experiment. Of these twelve, four students gave "no responses" for the light intensity variable.

Category B. Light Intensity: twenty students, or 16.8 per cent of the students, "missed the point completely."

Temperature Variable: twenty-four students, or 20 per cent of the students, "missed the point completely."

Category C. Light Intensity: fifty-four students or 45 per cent of the students responded with First Degree Relationships.

Temperature Variable: fifty-one students or 42.4 per cent responded with First Degree Relationships.

Category D. Light Intensity: twenty-six students or 21.8 per cent of all the students responded with Second Degree Relationships.

Temperature Variable: twenty-six students or 21.8 per cent responded with Second Degree Relationships.

Category E. Light Intensity: thirteen students or 10.8 per cent responded with Third Degree Relationships.

Temperature Variable: twelve students or 10 per cent responded with Third Degree Relationships.

CHAPTER IV

SUMMARY AND CONCLUSIONS

The purpose of this study was to determine what levels of comprehension science students develop during a teacher-pupil demonstration on photosynthesis. An experiment designed on the factors and variations of factors which affect the rates of photosynthesis in an Elodea plant was used to verify this assumption.

The research was carried out with 120 ninth-grade science students at Central Junior High School, Ames, Iowa. No attempt was made in grouping within the five classes, since they were the regular assigned groups taught by the investigator.

Each student was given a mimeographed brochure which contained recent research by scientists, and instructions on how the experiments were to be carried out. The students were all given a brief "refresher" course by the teacher so that they would have a common background of knowledge over photosynthesis. The students were assisted by the teacher during the setting up of the apparatus and were given only minimal assistance from then on. All students had to answer questions included in their brochure about the observations they made.

The key to this study was the type of conclusions or concepts the students developed during their experimenting.

The students had to verify their conclusions with the data they had collected. Some of the data had to be graphed and interpreted by the students. Each student was instructed to develop an understanding of his own and not rely on his fellow classmates for assistance.

All the notebooks were turned in and the concepts were compared with each other. They were individually categorized into five categories: A, B, C, D, and E.

Category A consisted of those responses which has "no responses" for their answers. This included 5.8 per cent of all the students. Samples are included in the Appendix. Category B consisted of those students "who missed the point completely." This group included approximately 18 per cent of all students. These students missed the main idea of the experiment, but still developed a scientific understanding closely related to the problem.

Category C consisted of those responses of First Degree Relationship level. These had a factual understanding of the effects of light intensity and temperature on the rates of photosynthesis. This included 44 per cent of all students. Category D consisted of those students who developed Second Degree Relationships or understandings with a direct mathematical relationship. This included 22 per cent of all the students.

Category E included those students who developed Third Degree Relationships of the understandings or concepts of highly developed mathematical and verbal understandings. This included 10 per cent of the students.

The final analysis verifies that approximately 95 per cent of all ninth-grade students at Central Junior High School developed some measurable scientific understandings during a teacher-pupil demonstration on photosynthesis, but at different levels of complexity of understanding.

A complete list of the various categories and samples of the understandings presented by the students will be found in the Appendix.

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APPENDIX

Student Responses

Category A. This group consists of those students who gave "no responses."

I don't understand.

I didn't understand it.

Don't understand.

I don't understand this stuff.

Don't get it.

No idea.

I don't understand this kind of science.

I don't get it.

I am afraid I cannot understand this at all.

Beats me.

Category B. This group gave "no relationship" responses.

I understand how to do it but cannot put it into words.

Plants are just as complex as humans, if not more so.

I think it is very interesting learning this way.

I think I understand it very well.

I think that from this experiment I am learning more than otherwise.

The Elodea plant does well at about 70 degrees, but most any other variable does poorly.

The more intense the heat at the same degrees, produces more bubbles at a faster rate.

The plant grows better in a warmer temperature of water but when it gets too hot it gradually dies.

This experiment shows how hot water can get before a plant will die.

The plant will start dying at a higher degree.

At too high of light power the plant dies because the cells are destroyed by intense light.

As the light is placed closer, more heat was generated and unusually more warmth in ideal conditions for life so more cells were produced causing more bubbles.

Category C. This group developed First Degree Relationships with a verbal understanding of the effects of light and temperature on photosynthesis.

The greater the light intensity, the greater the rate of photosynthesis.

The higher the temperature, the faster the photosynthesis takes place.

As the lamp was moved closer, the bubbles increased.

As the temperature increased, the plant produced more bubbles.

I found that bubbles develop under light intensity.

I found how many bubbles develop under certain degrees.

The temperature definitely has an effect on the oxygen output of the Elodea plant when the light intensity is static. This effect is, however, quite erratic and unpredictable.

In my opinion, light intensity affects the rate of photosynthesis depending on how close the light source is away from the plant.

Temperature and light intensity both influence the ability of Elodea plants to produce oxygen.

Plants give off oxygen. There usually are more bubbles given off the greater the light intensity.

The decrease of light intensity seems to decrease the number of bubbles produced.

The best combinations for producing oxygen seem to be 9600 to 12,800 candle power at 69 to 84 degrees Fahrenheit.

The absolute value difference in the number of bubbles per minute between two adjacent temperatures decreases as the candle power decreases.

Category D. This group is the Second Degree Relationships which have a direct mathematical and verbal understanding of the effects of light intensity and temperature.

The light intensity affects the rate of oxygen production in the Elodea plant. When the light intensity is doubled, the bubble count is raised two bubbles per minute.

The light intensity affects the bubbles of oxygen released by the Elodea plant when the temperature remains static. When the light intensity doubles, the oxygen bubbles per minute decreased by one or two bubbles.

The number of bubbles of oxygen produced by the Elodea plant per minute increased by two each time the light intensity doubles.

When the light intensity doubles, the Elodea plant emits two more bubbles per minute. Need more experiments to arrive at a definite answer.

It seems to me that after looking at the data, each individual plant, depending on size, conditions, position in the water and shape, has an amount of light in which it thrives best. Beyond this amount, or below it, it does not work as efficiently as it does when at that point.

The bubble rate per minute increases as you move the light closer to the Elodea plant. At three feet it has seven bubbles per minute, at six inches it has 18 bubbles per minute.

Six inches of water cuts the light intensity by one-half. The more the light intensity, the more the production of gas. The ideal range of temperatures is between 69 to 74 degrees Fahrenheit.

Category E. This group is the Third Degree Relationships which had some mathematical formulas developed to explain the relationships of light intensity and temperature on rates of photosynthesis.

An increase in light intensity, it seems, causes an increase in the rate of photosynthesis. As no leveling of the line is apparent, our data does not tell what is the minimum light intensity for maximum efficiency in photosynthesis. The Elodea plant's rate of photosynthesis increased in light intensity at the rate of one bubble per 1500 c.p. increase in light intensity. Perhaps due to an uneven flow of CO_2, the plant produced many less bubbles. More data is necessary before any conclusive results can be reached.

When the temperature increases 5 degrees, the average number of bubbles per minute is increased by 2 up to 79 degrees, then it decreases. The bubbles start out slowly but increase sharply till 79 degrees.

An increase in light intensity of 150 per cent increases the bubbles by two per minute. Any lesser increase has no direct effect.

For each 200 per cent difference in candle power, between the moves, there is a 7.8 difference in the number of bubbles emitted by the plants.

The one thing I can conclude is, regardless of equal candlepower on different plants, light traveling through a certain amount of water has less effect on the process of photosynthesis than light passing directly through air.

As far as I can see, this graph shows that the effect of light intensity upon photosynthesis is as predictable as the weather. A general mathematical equation could be made for the plants at 74 degrees Fahrenheit. For this situation, everytime the light increases one-half itself, the bubbles per minute increase by two. There are 12 bubbles per minute at 3200 candle power. When the light intensity doubles, the bubbles increase by two. When at 3200 triples, the number of bubbles increase four times itself. When 9600 is reached, it increases by 6. However at 6400 candle power, the bubbles increase only by 4. This throws my whole theory off. The light does have an effect on the number of bubbles per minute, and except for this one difference, the whole thing is a mess.